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Sensor Assembly, System Including RFID Sensor Assemblies, and Method

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INVENTORS

James R. Skorpik

Stephen R. Gosselin

Joe C. Harris

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Sensor Assembly, System Including RFID Sensor Assemblies, and Method

TECHNICAL FIELD

[0001] The invention relates to sensors. The invention also relates to valves and process control.

GOVERNMENT RIGHTS

[0002] This invention was made with government support under contract number DE-AC0676RLO1830 awarded by the U.S. Department of Energy. The Government has certain rights in the invention.

BACKGROUND OF THE INVENTION

[0003] Industrial process control environments typically require physical sensing of parameters such as temperature, pressure, flow rate, strain, displacement, humidity, vibration, etc. Adapting a sensor network and its cabling infrastructure to existing plant environments is usually cost prohibitive.

[0004] Various sensors that incorporate transmitters are known in the art. For example, U.S. Patent 5,774,048 (incorporated herein by reference) relates to a valve that generates a wireless transmittable signal if pressure drops within vehicle tires. U.S. Patent 6,005,480 to Banzhof et al. relates to similar subject matter.

[0005] U.S. Patent No. 6,199,575 to Widner (incorporated herein by reference) discloses a valve system that includes a MEMS pressure sensor that senses pressure and functions as a mechanical actuator for a valve. A transmitter is integrated with the valve and a receiver is located at a remote

location. A transmitter may be formed on the MEMS along with a pressure transducer and its associated circuitry. An alternative embodiment is disclosed in which a digital modulator is included in a transducer valve.

[0006] U.S. Patent No. 6,445,969 to Kenney et al. (incorporated herein by reference) discloses a system and method of monitoring process parameters associated with a manufacturing or testing process. This reference discloses that radio frequency identification tags may be used to transmit an event signal. If an event trigger is detected, a command is sent to a particular sensor to measure a specified process parameter.

[0007] U.S. Patent 6,484,080 to Breed discloses an acceleration sensor including an RFID unit. U.S. Patent 6,563,417 to Shaw discloses an RFID tag including a temperature sensor.

[0008] Pneumatic or fluid controlled valves are known in the art and used in a variety of applications, such as to control water and other fluids in nuclear reactors. Such valves are discussed in U.S. Patent No. 5,197,328 to Fitzgerald; U.S. Patent No. 6,026,352 to Burns et al.; U.S. Patent No. 5,329,956 to Marriott et al.; and U.S. Patent No. 5,774,048 to Achterholt, all of which are incorporated by reference. In a typical pneumatic operated valve, a current to pressure (I/P) transducer is coupled to a valve positioner which supplies an operating pneumatic pressure to a valve diaphragm actuator. The diaphragm actuator in turn is coupled to a sliding valve stem and plug. Feedback is provided by a mechanical linkage, such as by a valve positioner arm having one end connected to the actuator/valve stem and the other end coupled to the positioner so as to track movement of the valve stem. Alternatively, electrical signal feedback is provided from installed valve positioner instrumentation.

[0009] The value of sensor for providing both diagnostics and prognostics is readily accepted; however, innovative technical developments are needed to facilitate the implementation.

SUMMARY OF THE INVENTION

[0010] Some aspects of the invention provide a system comprising a valve; a plurality of RFID sensor assemblies coupled to the valve to monitor a plurality of parameters associated with the valve; a control tag configured to wirelessly communicate with the respective tags that are coupled to the valve, the control tag being further configured to communicate with an RF reader; and an RF reader configured to selectively communicate with the control tag, the reader including an RF receiver:

[0011] Other aspects of the invention provide a suite of RFID sensor assemblies for use in industrial process control. The suite can include, for example, sensors configured to sense one or more of temperature, pressure, strain, or other process control parameters. In some aspects of the invention, a tailored mechanical package is provided to allow the RFID tag to be readily adapted to a particular process component or parameter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Preferred embodiments of the invention are described below with reference to the following accompanying drawings.

[0013] Fig. 1 is a block diagram of a system including a pneumatically operated valve and a plurality of RFID sensor assemblies embodying various aspects of the invention.

[0014] Fig. 2A is a circuit schematic of a RFID sensor assembly.

[0015] Fig. 2B is a reader embodying various aspects of the invention.

[0016] Fig. 3 is a perspective view of an RFID sensor assembly in accordance with some embodiments.

[0017] Fig. 4 is a perspective view of an RFID sensor assembly in accordance with other embodiments.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0018] Fig. 1 shows a system embodying various aspects of the invention. The system 9 includes a fluid control or pneumatically operated valve 10. The air operated valve 10 includes a control valve 11, a pneumatic diaphragm actuator 12, a stem coupler 13, a valve positioner 14, a pressure or volume booster 15, a controller and I/P or E/P converter 16, a sensor 17, an air regulator 18, and a pneumatic fluid supply line 19. The valve 11 controls fluid flow through a main fluid line 20. The main fluid line 20 transfers fluid in connection with an industrial process. For example, the main fluid line could transfer fluid used in a power plant (e.g., water or other fluids used in a nuclear power plant). The fluid line 20 may be any other sort of fluid line in an industrial process facility.

[0019] In the illustrated embodiment, a condition of the fluid line 20 is sensed (e.g., temperature, pressure, flow) and this information is sent to the valve positioner 14. For example, in the illustrated embodiment, the sensor 17 is a pressure transducer that senses pressure upstream of the valve 11. In alternative embodiments, different parameters can be sensed either upstream or downstream of the valve 11. In the illustrated embodiment, an electro-pneumatic type valve positioner 47 is shown, including pneumatic positioner 14 and I/P

converter 16. The sensor 17 provides an output, which is an electrical output in the illustrated embodiment. More particularly, in the illustrated embodiment, the sensor 17 provides a current output. The converter 16 is coupled to the sensor (transducer) 17 and converts an electrical signal (current in the illustrated embodiment) from the sensor 17 to pressure. Other I/P or E/P converters could be employed. In some embodiments, the sensor 17 provides a signal that can be directly used by the valve positioner 14 and the converter 16 is omitted. In alternative embodiments, converter 16 can receive electrical signals from the valve position controller 39, from the sensor 17, or from both the valve position controller 39 and the process sensor 17. The valve position controller 39 is a remote controller, in some embodiments. The valve position controller 39 is a manually operable controller in some embodiments.

[0020] In the illustrated embodiment, the converter 16 is coupled to the valve positioner 14 which supplies an operating pneumatic pressure to the actuator 12. The diaphragm actuator 12 includes a diaphragm 21, and a spring 23 operating on the diaphragm. The diaphragm actuator 12 can be of a type that is opened by pneumatic fluid and closed by the spring, or can be of a type that is closed by a pneumatic fluid and opened by the spring. The actuator 12 is coupled to a sliding valve stem 24 and to the control valve 11. The spring 23 is biased between the valve stem 24 and the diaphragm 21. Feedback is provided by the actuator-valve stem coupler 13 which has one end connected to the valve stem 24 and another end coupled to the positioner 14 so as to track movement of the valve stem 24. As the valve 11 approaches the closed position, feedback is used to seat the valve 11 without slamming. The regulator valve 18 merely

reduces pressure from pneumatic supply line 19 and booster 15 merely increases pressure to a level required to operate the pneumatic actuator 12.

[0021] Alternative arrangements are possible. For example, while the pneumatic actuator 12 shown in Fig. 1 is a direct-acting pneumatically operated diaphragm actuation, in which increasing pneumatic pressure pushes down on the diaphragm 21 extending the actuator stem 24, alternative actuator types could be employed. For example, in one alternative embodiment (not shown), a reverse-acting pneumatically operated diaphragm actuator type is employed in which increasing pneumatic pressure pushes up on the diaphragm and retracts the actuator stem. In another alternative embodiment (not shown), a reversible type pneumatic actuator is employed that can be assembled and installed as either a direct-acting or reverse-acting type pneumatic actuator.

[0022] Similarly, while an electro-pneumatic type valve positioner 47 is shown in Fig. 1, including pneumatic positioner 14 and I/P converter 16, alternative embodiments are possible. For example, while an analog type electro-pneumatic positioner 14 is shown in Fig. 1, a digital electro-pneumatic positioner is used in alternative embodiments. Further, in some applications a pneumatic type positioner will be used. In these embodiments, the pneumatic positioner 14 receives a pressure input signal directly from the process sensor 17 or valve position controller 166.

[0023] In some embodiments, a plurality of RFID sensor assemblies is provided to establish on-line self-diagnostic, prognostic, and calibration capabilities for the pneumatically operated valve. To instrument a component such as the pneumatically operated valve 10, individual RFID sensor assemblies are attached to monitor various parameters. Various RFID sensor assemblies

may have unique sensor interfaces. More particularly, the RFID sensor assemblies include mounting structure such that the mounting and sensing is noninvasive to normal valve operation. Some such mounting structures are described below in connection with Figs. 3 and 4.

[0024] The RFID sensor assemblies are used, in the embodiment of Fig. 1, to provide on-line or in-use self-diagnostic, prognostic, and calibration capabilities for pneumatically operated process control valves and control system components. For example, RFID sensor assemblies can be coupled to or proximate (e.g., upstream or downstream of) components such as, for example, the I/P or E/P converter 16, the valve positioner 14, the pressure or volume booster 15, the actuator spring 23, the packing of the control valve 11, and the fluid supply regulator valve 18. In Fig. 1, an RFID sensor assembly 31 is coupled to an electrical conductor 41 between the converter 16 and the valve positioner 14, an RFID sensor assembly 32 is coupled to the actuator-valve stem coupler 13, an RFID sensor assembly 33 is coupled to a conduit 22 between the booster 15 and the pneumatic actuator 21, an RFID sensor assembly 34 is coupled to a conduit 43 between the valve positioner 14 and the booster 15, an RFID sensor assembly 35 is coupled to a conduit 45 between the valve positioner 14 and regulator valve 18, an RFID sensor assembly 36 is coupled to pneumatic supply line 19 between feeds to the regulator valve 18 and to the booster 15, and RFID sensor assemblies 37 are coupled to the process line or conduit 20 on either side of the control valve 11.

[0025] The use of RFID sensor assemblies 31-37 allows for condition monitoring (e.g., periodic monitoring and data logging) of important valve performance parameters such as valve seating force, spring 23 preload and

spring constant, bench set, spring packing drag or bearing friction loads, linearity of the spring 23, condition of the diaphragm 21, and valve 11 position, stroke times, and calibration. Bench set comprises compression on the spring.

[0026] In the illustrated embodiment, the system 9 further includes an RFID control tag 38, and each of the RFID sensor assemblies 31-37 communicates to the control tag 38. This is, in some embodiments, a bi-directional link so that the control tag 38 can request data from the RFID sensor assemblies 31-37 and also communicate with a reader. The system 9 further includes a reader 40 defined by, for example, a portable computer 42 such as a laptop or personal digital assistant plus an RF receiver or module 44 coupled to the laptop or personal digital assistant for communication with the laptop or personal digital assistant. Communication can be via an RS-232 link, PCMCIA connection, serial port, or other communication link. In the illustrated embodiment, the computer 42 includes software that allows for data transfer from the control tag 38 and/or the RFID sensor assemblies 31-37. The software (or separate software) permits setting up the tags.

[0027] In other embodiments, the RFID sensor assemblies 31-37 communicate directly with the reader, instead of through the control tag 38.

[0028] In the illustrated embodiment, the RF link between the reader 40 and the control tag 38 (and/ or the sensor assemblies 31-37) is a low power link. For example, low power is used for transmissions. This allows the read/write range to be restricted to a predetermined range. The restricted read/write range allows for multiple networks to be placed in zones or grids, much like cell phone grids, without crossover RF interference.

[0029] The tags have individual IDs, only tags with requested IDs will respond. In the illustrated embodiment, the tags and reader operate in a frequency band that does not require government licensing such as the ISM (industrial scientific measurement) band in the U.S. or frequency bands that similarly do not require government licensing in other countries.

[0030] The RFID sensor assemblies 31-37 could be or include, in some embodiments, RFID tags that are the same as or substantially similar to the RFID tags described in the following patent applications, which are incorporated herein by reference: U.S. Patent Application Attorney Serial No. 10/263,826, filed October 2, 2002, entitled "Radio Frequency Identification Device Communications Systems, Wireless Communication Devices, Wireless Communication Systems, Backscatter Communication Methods, Radio Frequency Identification Device Communication Methods and a Radio Frequency Identification Device" by inventors Michael A. Hughes and Richard M. Pratt; U.S. Patent Application Serial No. 10/263,809, filed October 2, 2002, entitled "Method of Simultaneously Reading Multiple Radio Frequency Tags, RF Tag, and RF Reader", by inventors Emre Ertin, Richard M. Pratt, Michael A. Hughes, Kevin L. Priddy, and Wayne M. Lechelt; U.S. Patent Application Serial No. 10/263,873, filed October 2, 2002, entitled "RFID System and Method Including Tag ID Compression", by inventors Michael A. Hughes and Richard M. Pratt; U.S. Patent Application Serial No. 10/264,078, filed October 2, 2002, entitled "System and Method to Identify Multiple RFID Tags", by inventors Michael A. Hughes and Richard M. Pratt; U.S. Patent Application Serial No. 10/263,940, filed October 2, 2002, entitled "Radio Frequency Identification Devices, Backscatter Communication Device Wake-Up Methods,

Communication Device Wake-Up Methods and A Radio Frequency Identification Device Wake-Up Method", by inventors Richard Pratt and Michael Hughes; U.S. Patent Application Serial No. 10/263,997, filed October 2, 2002, entitled "Wireless Communication Systems, Radio Frequency Identification Devices, Methods of Enhancing a Communications Range of a Radio Frequency Identification Device, and Wireless Communication Methods", by inventors Richard Pratt and Steven B. Thompson; U.S. Patent Application Serial No. 10/263,670, filed October 2, 2002, entitled "Wireless Communications Devices, Methods of Processing a Wireless Communication Signal, Wireless Communication Synchronization Methods and a Radio Frequency Identification Device Communication Method", by inventors Richard M. Pratt and Steven B. Thompson; U.S. Patent Application Serial No. 10/263,656, filed October 2, 2002, entitled "Wireless Communications Systems, Radio Frequency Identification Devices, Wireless Communications Methods, and Radio Frequency Identification Device Communications Methods", by inventors Richard Pratt and Steven B. Thompson; U.S. Patent Application Serial No. 10/263,635, filed October 4, 2002, entitled "A Challenged-Based Tag Authentication Model", by inventors Michael A. Hughes and Richard M. Pratt; U.S. Patent Application Serial No.09/589,001, filed June 6, 2000, entitled "Remote Communication System and Method", by inventors R. W. Gilbert, G. A. Anderson, K. D. Steele, and C. L. Carrender; U.S. Patent Application Serial No. 09/802,408; filed March 9, 2001, entitled "Multi-Level RF Identification System"; by inventors R. W. Gilbert, G. A. Anderson, and K. D. Steele; U.S. Patent Application Serial No. 09/833,465, filed April 11, 2001, entitled "System and Method for Controlling Remote Device", by inventors C. L. Carrender, R. W. Gilbert, J. W. Scott, and D. Clark; U.S. Patent Application

Serial No. 09/588,997, filed June 6, 2000, entitled "Phase Modulation in RF Tag", by inventors R. W. Gilbert and C. L. Carrender; U.S. Patent Application Serial No.09/589,000, filed June 6, 2000; entitled "Multi-Frequency Communication System and Method", by inventors R. W. Gilbert and C. L. Carrender; U.S. Patent Application Serial No. 09/588,998; filed June 6, 2000, entitled "Distance/Ranging by Determination of RF Phase Delta", by inventor C. L. Carrender; U.S. Patent Application Serial No. 09/797,539, filed February 28, 2001, entitled "Antenna Matching Circuit", by inventor C. L. Carrender; U.S. Patent Application Serial No. 09/833,391, filed April 11, 2001, entitled "Frequency Hopping RFID Reader", by inventor C. L. Carrender.

[0031] The RF tags offer significant features at the sensors. The tags include microprocessors. In the illustrated embodiments, the microprocessors allow for calibration, compensation, preprocessing, and onboard diagnostics and prognostics. Each tag includes a large amount of nonvolatile memory. In some embodiments, the RFID tags are used as data loggers. The tags use the memory to periodically or at various times store data that is measured by the sensors. The nonvolatile memory is also used to store setup information that is particular to the type of sensor and the tag application requirements. For example, the time period for acquiring data is user settable (e.g., times when data is to be taken and frequency of data logging within specified time ranges). Each control tag and RFID tag included in the assemblies 31-37 has its own unique identification code or ID which is a main element in the RF protocol for communications. In some embodiments, the RF link between the reader 40 and the control tag or RFID assembly 31-37 is two way (RF reader 40 request tag to transmit). In other embodiments, the RF link between the reader 40 and the

control tag or RFID assembly 31-37 is one way (tag periodically transmits to an RF reader). In some embodiments, the reader 40 is coupled to (or selectively coupled to) the Internet and defines a web server so that process reporting is performed via web pages and so that users can monitor process parameters using web browsers. Alternatively, data from the reader 40 is transferred at times to a web server 46 separate from the reader.

[0032] The system of Fig. 1 can be adapted for use with either sliding stem or rotary stem control valves and actuator assemblies with either pneumatic or electromagnetic controllers.

[0033] Another RFID sensor assembly design is shown in Fig. 2A. The RFID sensor assemblies are relatively small. The RFID sensor assembly 50 that is shown in Fig. 2A is configured to sense temperature and impact (acceleration). Other parameters are sensed in alternative embodiments. The RFID sensor assembly 50 includes a processor 54 that can accommodate both analog and digital sensors. In the illustrated embodiment, the processor 54 is a Texas Instruments 430x325 integrated circuit microprocessor. Other embodiments are possible. A thermocouple 53 and a temperature sensor 55 are coupled to the microprocessor. In the illustrated embodiment, the thermocouple 53 is a high temperature thermocouple. Other temperature sensors are possible. The system 50 further includes an impact sensor or accelerometer 57 coupled to the processor 50; e.g., via a buffer op-amp.

[0034] The assembly 50 further includes an RF transceiver 56 coupled to the processor 54 and to an antenna 58. The assembly 50 further includes a low power RF detector 60 configured to provide a wakeup signal to the processor 54.

[0035] The assembly 50 further includes a battery 62 coupled to the integrated circuit 54 to supply power to various components of the assembly 50 that require electrical power. In the illustrated embodiment, the assembly 50 includes a power supervisor 64 coupled to a reset input of the integrated circuit 54 and a power on/off switch 66 coupled between the power supervisor 64 and the battery 62. The assembly 50 further includes a battery monitor 68 coupled to the integrated circuit 54 and configured to monitor the condition of the battery. In the illustrated embodiment, the assembly 50 further includes a super capacitor or ultracapacitor 70 and an LDO regulator 72 having an input coupled to a positive terminal of the ultracapacitor 70. The input of the LDO regulator 72 and the positive terminal of the super capacitor 70 are also coupled to the on/off switch 66. The LDO regulator 72 has an output that provides a regulated voltage to the various electronic components of the assembly 50. The ultracapacitor 70 provides supplemental power for RF communications and allows continued operation when the battery 62 is replaced. The components of the assembly 50 other than the battery 62 and thermocouple 53 are enclosed in a common housing 74 and the battery 62 is enclosed in a housing 76 that is removable from the housing 74. The components enclosed in the housing 74 and in the housing 76, and the housings 74 and 76 together can be referred to as an RFID tag 51.

[0036] In some embodiments, sensors such as strain gauges and/or LVDTs are used. In such embodiments, interface circuitry is provided between the sensor and the microprocessor 54.

[0037] The reader 52 (Fig. 2B) includes a transceiver 78 configured to communicate with the transceiver 56 (Fig. 2A). The reader 52 further includes a processor 80 coupled to the transceiver 78. In the illustrated embodiment, the

processor 80 is a Texas Instruments 430x325 integrated circuit microprocessor. The reader 52 further includes a battery 82. The reader 52 further includes an LDO regulator 84 configured to provide a regulated voltage to electrical components of the reader 52. The reader 52 further includes an on/off switch 86 coupled between the battery 82 and the LDO regulator 84. The reader 52 also includes an interrogate switch 88 which, when actuated, causes the reader 52 to interrogate the tag assembly 50 (Fig. 2A). The reader 52 further includes input/output interfaces such a display 90.

[0038] In the illustrated embodiment, the reader 52 further includes a low battery indicator, a power on indicator 92, and a speaker 96. Other embodiments are possible.

[0039] In the illustrated embodiment, the reader 52 is configured to be coupled to a PDA or portable computer. In alternative embodiments, the reader 52 is coupled to or incorporated in a PDA or portable computer and uses the display and/or speaker, and/or keyboard or input interface of the PDA or computer.

[0040] Some aspects of the invention provide a suite of RFID sensor assemblies for sensor use in industrial process control. The suite can include, for example, sensors configured to sense one or more of temperature, pressure, strain, or other process control parameters. In some aspects of the invention, a tailored mechanical package or mounting structure is provided to allow the RFID tag to be readily adapted to a particular process component or parameter.

[0041] For example, Fig. 3 is a perspective view of a sensor assembly 150, which can be substantially similar to the RF tag assembly 50 shown in Fig. 2A. The sensor assembly 50 includes an RFID tag 151, which can be identical

to or substantially identical to the RFID tag 51 shown in Fig. 2A. The assembly 151 is configured to be used to measure temperature and may be placed in a high temperature environment. The assembly 151 includes a probe or waveguide 152 having first and second ends 153 and 154. The first end 153 defines a tip, and a thermocouple 155 is supported on the tip. The RFID tag 151 is supported on the second end 154.

[0042] An RFID sensor assembly for use with a fluid conduit such as one used in a nuclear reactor includes a band that encircles the fluid conduit 156, and an RFID tag supported by the band. The sensor assembly can be for sensing temperature, such as the sensor assembly 150 shown in Fig. 3. The RFID sensor assembly 150 is for use with a fluid conduit 156 and includes a band 157 that encircles the fluid conduit 156, and an RFID tag 151 supported by the band 157.

[0043] An RFID sensor assembly 200 for use in sensing pressure is shown in Fig. 4 and includes a gas inlet port 202 configured to be coupled to a port on a conduit 206. For example, the gas inlet port, in some embodiments, is configured to be coupled (mechanically mated) to an ancillary port or threaded stub on a flow pipe.

[0044] A variety of additional RFID sensor assembly designs is contemplated, the above specific designs being provided by way of example. Each RFID sensor assembly includes a mating adaptor that allows for ease of installation and minimization of modification to existing process control components. Some RFID sensor assemblies just sense switch closures such as for limit switches or relay contacts.

[0045] The ability to locally add desired sensing to an industrial process provides tremendous flexibility for continually adding to, modifying, or enhancing a sensor network.

[0046] In compliance with the statute, the invention has been described in language more or less specific as to structural and methodical features. It is to be understood, however, that the invention is not limited to the specific features shown and described, since the means herein disclosed comprise preferred forms of putting the invention into effect. The invention is, therefore, claimed in any of its forms or modifications within the proper scope of the appended claims appropriately interpreted in accordance with the doctrine of equivalents.